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BLAST PRESSURES BEHIND $3\frac{1}{4}$-INCH, 5-INCH HIGH-VELOCITY, AND $11\frac{3}{4}$-INCH AIRCRAFT ROCKETS

by

Paul Tamarkin, Ph.D. and Thomas A. Perls, Ph.D.

ABSTRACT

Preliminary data are presented on the pressures and temperatures associated with the blast from representative types of aircraft rockets, as well as on the resulting accelerations of two control surfaces on a TBM-3 airplane. The blast pressures were found to consist of an initial positive peak, possibly followed by a longer negative phase, followed in turn by a phase of oscillatory pressures to which no definite frequency could be assigned. The limitations of the pressure-measuring channels are set forth, and design criteria are evolved for instrumentation to be used in airborne measurement of rocket-blast pressures.

INTRODUCTION

Upon repeated firings of rockets from various types of naval aircraft, structural failures have occurred in the control surfaces of wings and tail assemblies. In order to obtain data on which to base designs for control surfaces strengthened so as to withstand the blast behind rockets when they are fired, the Bureau of Aeronautics requested the David Taylor Model Basin to make preliminary investigations of the pressure-time histories of the blast pressures behind rocket motors.* Accordingly tests were carried out with two objectives in mind: (a) to determine the orders of magnitude of the pressures, frequencies, durations, and temperatures of the blast phenomena associated with the firing of aircraft rockets, and (b) to determine criteria on which to base the design and development of instrumentation to be used in extended research on rocket-blast pressures.

The instrumentation used for the pressure measurements in these tests was necessarily makeshift and consisted of modifications of equipment ordinarily used for the measurement of gun-blast pressures. It was not found possible to use a single measurement channel to record both the high-frequency components and the general long-duration character of the rocket blast. By using two types of channels on every rocket firing, it was hoped that enough information could be pieced together to fulfill the above objectives.

*See References 1 through 5. These and other references are listed on page 34.

The tests included blast measurements from rockets of representative types fired from a stationary TBM-3 airplane and from specially constructed test stands.

The tests were conducted at the Armament Test Unit of the U. S. Naval Air Station, Patuxent River, Maryland. They were begun in December 1944 and completed in April 1945.

INSTRUMENTATION

The instrumentation used included diaphragm blast gages to measure pressures, copper-constantan thermocouples to measure temperatures associated with the blast, and Westinghouse quartz-crystal accelerometers to measure the accelerations of the wing flap and elevator of the airplane from which the rockets were fired.

Pressure Gages

The diaphragm blast gage,[6] shown in Figure 1, consists essentially of a pressure-sensitive diaphragm backed by a sealed compartment containing air at a pressure of 1 atmosphere. The diaphragm acts as a flat, fixed-edge circular plate having a characteristic deflection pattern and a natural frequency dependent on its composition, thickness, and diameter. Two modifications of the gage were used, one to measure short-duration pressures and the other to measure long-duration pressures. In the first, a strain element made of a single-layer, spirally wound, noninductive coil of 1-mil Advance wire with a resistance of 500 ohms was cemented to the inner face of the diaphragm. The second modification had two spiral strain elements, each with a resistance of 120 ohms. One element was cemented to the inner side, and the other to the outer side, of the diaphragm.

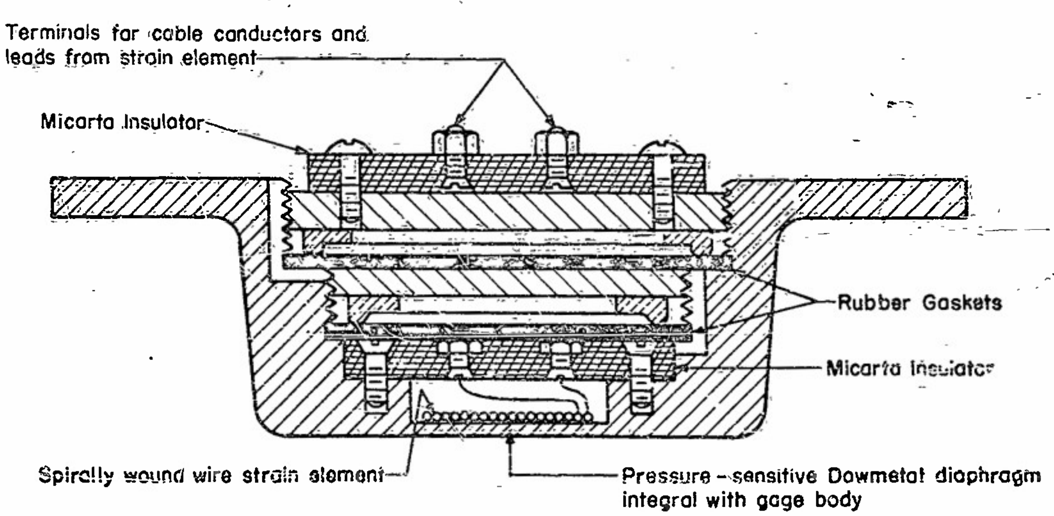


Figure 1 - Diaphragm Blast Gage

In both gage modifications the pressure to be measured produces a deflection of the diaphragm. The attached spiral strain elements, which respond to the tangential strains in the diaphragm, undergo a change of resistance. When a current is sent through the strain element, the resistance change produces a voltage variation which is amplified and recorded.

The diaphragm blast gage is sensitive to temperature. This is especially true of the single-element modification but also, to a considerable extent, of the double-element gage—even though good temperature compensation between the two elements is to be expected for quasi-static temperature changes. The compensation is far from complete for dynamic changes, because the two elements—one on the inside and the other on the outside of the diaphragm—are subjected to different dynamic temperatures. It will later be shown that the temperature effect on the short-duration gage introduces some uncertainty into the determination of the positive impulse in the rocket records. With the long-duration gage, the transient temperatures from rocket blast have considerable time to act and thus tend to affect seriously the later phases of the pressure record. To overcome this drawback, a very thin sheet of asbestos paper was placed over the diaphragm and cemented to the shoulder of the diaphragm in such a manner as to leave free the pressure-sensitive portion of the diaphragm. A piece of airplane fabric was then cemented to the gage case over the asbestos in order to keep the blast from tearing off the asbestos. This device was tested and found to give considerably improved protection from heat. It was also found, however—in the course of gun-blast tests conducted with both bare and asbestos-covered gages—that the asbestos striking the diaphragm added to the peak pressure by about 10 percent. This effect is of no consequence since only the long-duration pressures are considered to be reliably recorded by the double-element gage which uses a relatively low-frequency electronic channel.

The use of two types of channels, one capable of recording high-frequency (up to about 15,000 cps) pressures for durations of about 25 milliseconds and the other capable of recording low-frequency pressures (under 150 cps) for indefinitely long durations, was necessitated by the inherent inability of one diaphragm blast gage and its associated channel to measure pressures ranging through the frequency spectrum from 0 to 15,000 cps. On the other hand, it was important to scan this whole spectrum because the nature of the rocket blast being measured was unknown. As a result, the use of two recording channels—a high-frequency, short-duration one, and a low-frequency, long-duration one—was necessitated.

Instrumentation for short-duration pressures. The block diagram for the recording channel associated with the single-element blast gage is shown in Figure 2. The strain element forms one arm of a Wheatstone bridge

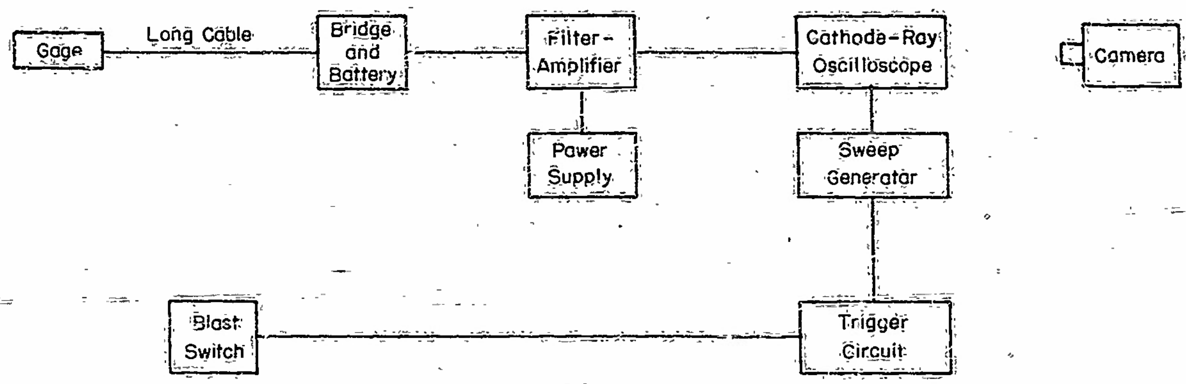


Figure 2 - Block Diagram of Recording Channel of Single-Element Gage for Recording Short-Duration Pressures

whose output is connected to a preamplifier containing an electronic filter circuit. This filter-amplifier may be tuned sharply so as to attenuate almost completely the spurious signal due to the resonant vibration of the gage at its natural frequency. These vibrations are usually set up by shock excitation and interfere with the proper interpretation of the pressure record. The filter-amplifier is, in turn, connected to the amplifiers in a DuMont Type-208 cathode-ray oscilloscope. A TMB sweep generator supplies a linear time base to the electron beam of the oscilloscope. The sweep is initiated by means of a blast-sensitive switch placed between the source of blast and the gage. This switch is part of a circuit containing a battery and a resistor across which is developed a voltage pulse which triggers the sweep generator. The trace on the cathode-ray tube is photographed by means of a Kodak Ektra camera with F/1.9 Ektar lens. Some records are photographed by means of a General Radio Class-651 moving-film oscilloscope camera; the time base on these records being supplied by the motion of the film rather than by the sweep generator.

The gage with the single strain element and its associated amplifying and recording channel had a frequency response essentially flat up to 15,000 cps and was used chiefly to determine the rapid pressure fluctuations in the first 25 milliseconds. Since the electronic system had a time constant of approximately 150 milliseconds, the low-frequency components of the pressures recorded after the first 25 milliseconds were probably seriously distorted.

Instrumentation for long-duration pressures. In order to obtain the ressure history after the first 25 milliseconds, a double-element modification the diaphragm gage was used. This gage was attached to a TMB Type 1-A strain indicator[7] whose output was coupled to a string oscillograph. The block diagram for the modified diaphragm gage and its associated channel is given in Figure 3. The strain indicator consists essentially of an a-c bridge, two

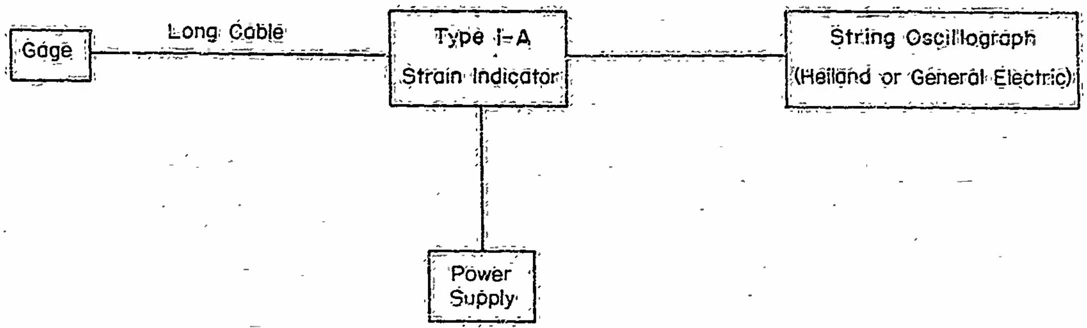


Figure 3 - Block Diagram of Recording Channel of Double-Element Gage for Recording Long-Duration Pressures

active arms of which are formed by the strain elements cemented to the gage diaphragm. The bridge voltage is supplied by a 2200-cps oscillator. The output of the bridge is coupled into a 3-stage amplifier, which is followed by a mixer and phase discriminator stage (to differentiate between compression and tension of the diaphragm). These, in turn, are followed by a dual demodulating and a rectifying stage whose output is connected to a string oscillograph. The response of the strain indicator is approximately flat up to 150 cps, and the output current is linear to 6 milliamperes.

Two types of string oscillographs were used. One was a Heiland Type-A104R 6-channel oscillograph, with string galvanometers having a natural frequency of 100 cps and a frequency response flat up to 60 cps. These galvanometers were shunted to reduce their deflection sensitivity. The other was a General Electric 6-channel string oscillograph. The strings in this instrument had a resonant frequency of 1200 cps and a response flat up to about 500 cps. Both oscillographs had built-in timing devices which drew lines across the film at intervals of 10 milliseconds.

Thermocouples

In order to measure the temperatures associated with the blast behind rocket motors, copper-constantan thermocouples were used. These were made of 4-mil copper wire and 3-mil constantan wire. As shown in Figure 4, the wires were mounted between two blocks of wood, which were bolted together and shellacked; the "hot" junction* protruded from between the blocks about 1/25 inch,

*The conventional terms "hot" and "cold" junctions of the thermocouple are used for the active and insulated junctions respectively.

and the "cold" junction was completely inside the block. It was assumed that the duration of the transient temperatures would be short enough to preclude a significant rise of temperature inside the wooden block at the location of the cold junction. The thermocouple signal was recorded directly on a sensitive galvanometer string of the Heiland oscillograph to which it was connected by a long cable.

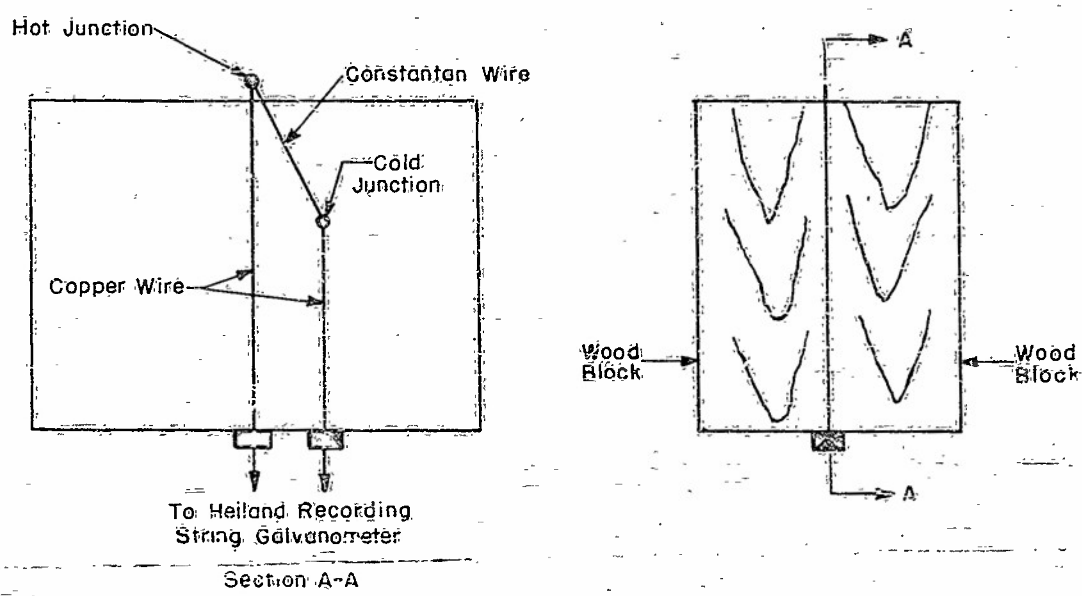


Figure 4 - Schematic Diagram of Thermocouple

Each thermocouple was calibrated before assembly in the wooden blocks by placing the cold junction in a beaker of water at room temperature and immersing the hot junction in another beaker of water which was heated by a hot plate. Simultaneous readings were taken of the temperature of the water and the current through the thermocouple. The temperature of the water containing the hot junction was varied from room temperature up to 100° C. The value of the thermocouple sensitivity over this range was found to be constant, and was assumed to apply even above this range since high accuracy in the measurement of rocket-blast temperatures was not essential.

Accelerometers

Accelerations of the wing flap and elevator were measured by a quartz-crystal accelerometer of the Westinghouse type.[8,9] A schematic diagram of the accelerometer is shown in Figure 5. The accelerometer had a natural frequency of 20,000 cps. It was connected by a short length of shock-resistant cable to a nearby cathode-follower impedance coupler and natural-frequency filter which, in turn, was connected by a cable to a DuMont Type-208 blue-trace cathode-ray oscilloscope.

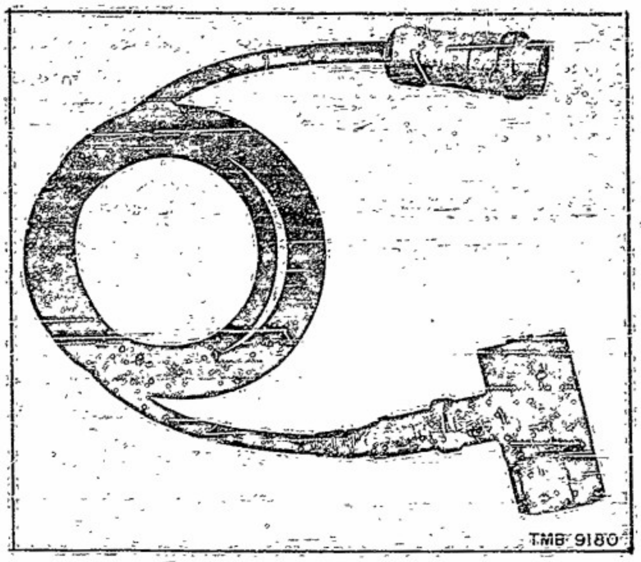


Figure 5a - Crystal Accelerometer with Shock-Resistant Cable

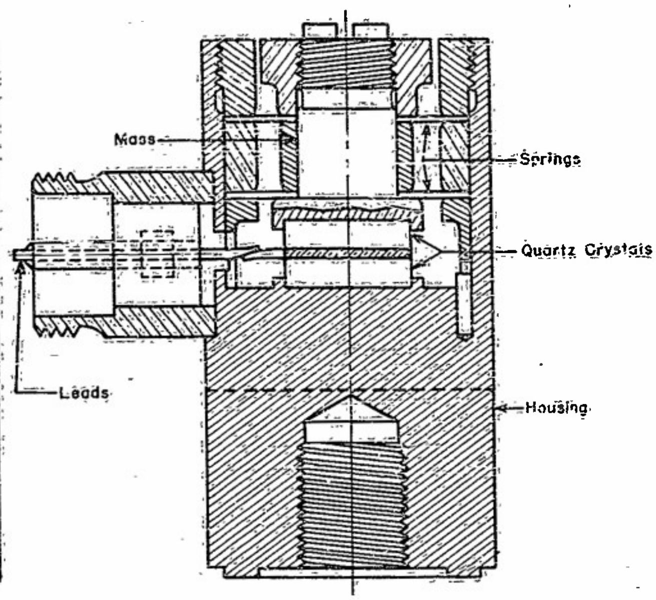


Figure 5b - Diagram of Accelerometer

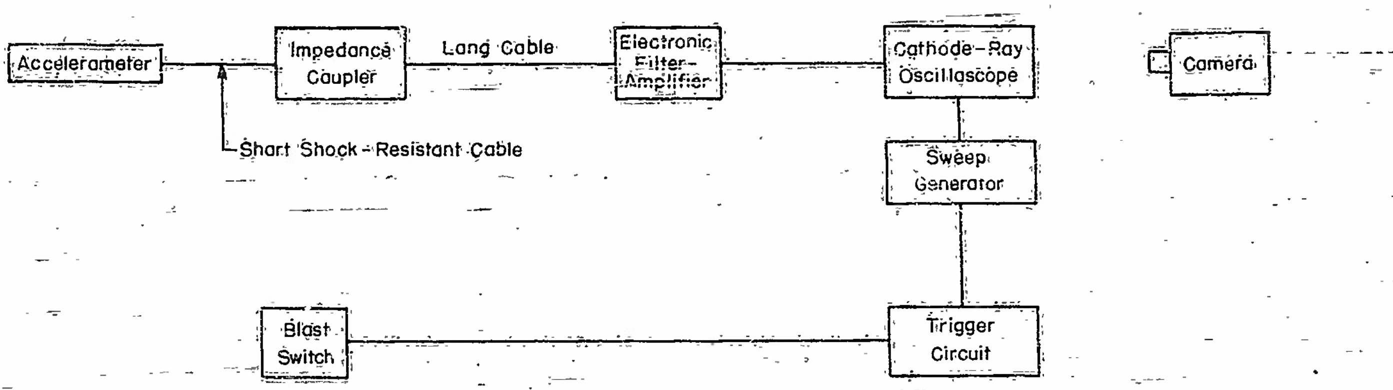


Figure 5c - Schematic Diagram of Crystal Accelerometer Circuit

Figure 5 - Crystal Accelerometer

TEST PROCEDURE

The most direct way of determining the rocket-blast pressures on an airplane surface is to fire the rocket from the airplane in flight. Since no simple way could be found to take airborne measurements with this preliminary instrumentation, some good approximation to this method had to be used. Except for the effects of air speed, altitude, and ambient temperature, it was felt that good preliminary results could be obtained by firing the rockets from under the wing of a plane, while the plane itself was lifted a few feet off the ground. At the same time, it was thought that future ground testing could be considerably simplified if it could be shown that some simple testing stand could replace the lifted airplane without seriously affecting the blast-pressure records.

The actual tests consisted of three parts:

1. Measurements of the rocket blast from $3\frac{1}{4}$-inch aircraft rockets (AR) and 5-inch high-velocity aircraft rockets (HVAR) at positions in a testing stand simulating positions on airplane control surfaces.

2. Measurements of the blast from these rockets at positions on the control surfaces of a TBM-3 type airplane.

3. Pressure measurements of the blast from $11\frac{3}{4}$-inch AR's ("Tiny Tims") at simulated SB2C airplane positions.

Measurements obtained at simulated airplane positions will hereafter be designated as measurements of "field" pressures. Simultaneously with measurements of the field blast pressures, temperatures were measured at the pressure-gage locations. Accelerations of the wing flap and the trailing edge of the elevator were measured along with the blast pressures during the rocket firings from the airplane by mounting an accelerometer beside the pressure gages.

Measurements at Simulated TBM-3 Airplane Positions

Blast and temperature from $3\frac{1}{4}$-inch AR's and 5-inch HVAR's were measured in the following manner. A board was attached to a rocket launching platform above the rocket, Figure 6a. This board extended aft of the rocket nozzle, and two gages were mounted one behind the other at the end of the board. This gage position simulated a point which would be directly behind a rocket and in the trailing edge of the wing flap of a TBM-3 airplane. To simulate a position in the elevator control surface of the same airplane, two gages were placed in a baffle 22 feet behind the rocket nozzle (Figure 6b) and at such a height that the gages were 4 feet above the rocket axis extended when the rocket was in its firing position. A diagram of these positions is shown in Figure 6c.

In general the gage positions were such that their geometry with respect to the rockets corresponded to that which would exist for chosen positions in the control surface of a TBM-3 airplane. For each rocket firing, as shown in Figure 6d, the stand was lifted in the air so that the rocket was about 11 feet above the ground. This was done to delay the effects of reflection of the blast from the ground. Several series of rounds were fired, with various combinations of the two types of gages being used so as to obtain the complete pressure history at each location.

Temperatures from the firing of $3\frac{1}{4}$-inch AR's and 5-inch HVAR's were obtained by mounting two thermocouples on the board beside the pressure gages at the simulated flap position

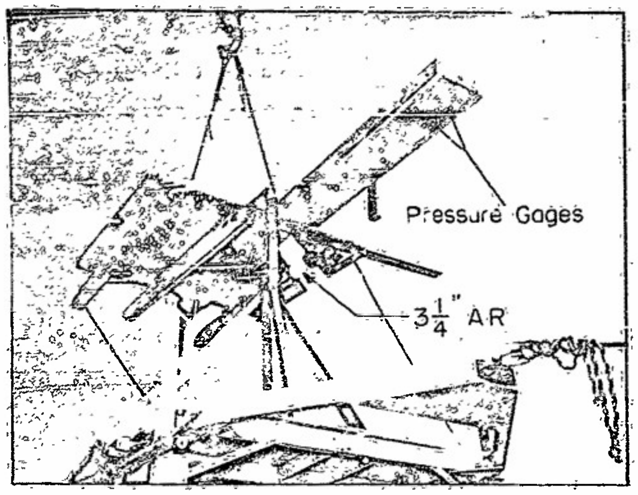


Figure 6a - Simulated Flap Position

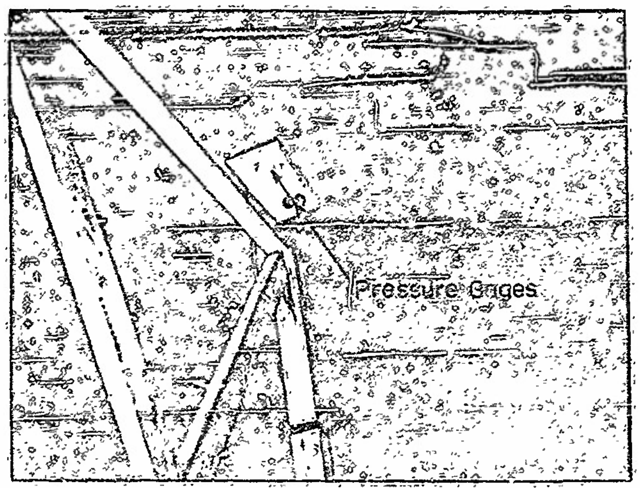


Figure 6b - Simulated Elevator Position

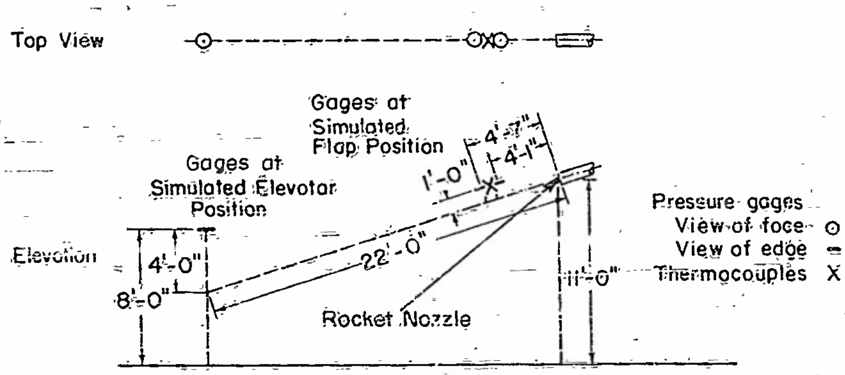


Figure 6c - Pressure Gage and Thermocouple Positions

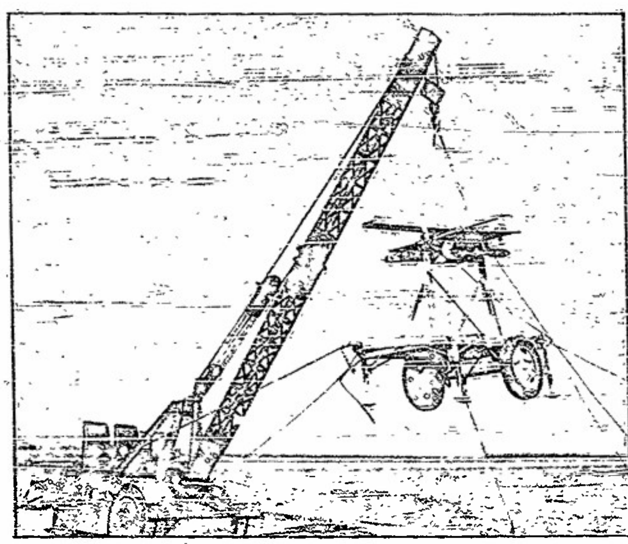


Figure 6d - Rocket Stand Ready for Firing a $3\frac{1}{4}$-Inch AR

Figure 6 - Field Measurements on $3\frac{1}{4}$-Inch AR's and 5-Inch HVAR's

Measurements on Control Surfaces of a TBM-3 Airplane

During the firing of $3\frac{1}{4}$-inch AR's and 5-inch HVAR's, rocket-blast pressures on the TBM-3 airplane and the resulting accelerations were measured as follows: There were essentially two gage positions, one in the starboard wing flap and one in the starboard elevator control flap. There were two gages at each position, one with its diaphragm flush with the lower surface of the member, and one with its diaphragm flush with the upper surface. The gages flush with the upper surface were intended to determine the magnitude of the diffracted pressures. The first gage position shown in Figures 7a and 7b was as close to the trailing edge of the flap as possible and almost directly behind the rocket nozzle. The second gage position, shown in Figures 7c and 7d, was just aft of the hinge of the elevator and as near the outboard edge as possible. Several series of shots were fired using various combinations of the two types of gages, short and long duration, in order to obtain a representative picture of the pressures acting at the lower and upper surfaces of the trailing edge of the flap, and the lower and upper surfaces of the elevator. During these firings, the airplane was lifted about 12 feet into the air in order to delay the effects of reflection from the ground. The raised plane is pictured in Figure 7e.

To measure the accelerations of the wing flap and elevator under the action of rocket blast, accelerometers were bolted to the cases of the downward-oriented pressure gages so as to measure the vertical component of the acceleration. A typical accelerometer mounting can be seen in Figure 7d.

Salvo Firings

An additional test was conducted to determine the pressures acting on the lower surface of the wing flap upon the firing of four 5-inch HVAR's simultaneously.

Effect of Launching Angle

Another subsidiary test was conducted to determine the effect of varying the rocket launching angle on the pressures acting on the wing flap. The nose of the rocket was raised or lowered so that the angle between the new rocket axis and the old was plus 4 or minus 4 degrees, respectively.

Measurements at Simulated SB2C Airplane Positions

The last portion of the test dealt with the measurements of blast pressures and associated temperature from $11\frac{3}{4}$-inch AR's. The pressures were

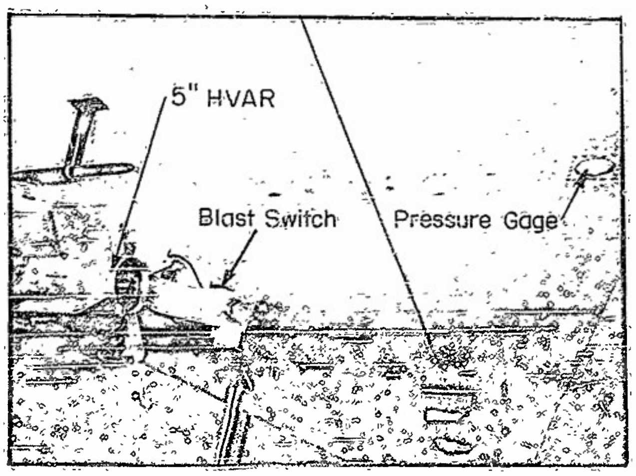


Figure 7a - Gage Position in Lower Surface of Flap

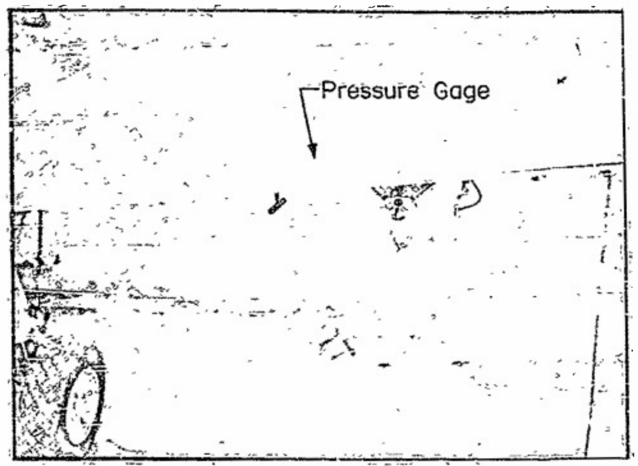


Figure 7b - Gage Position in Upper Surface of Flap

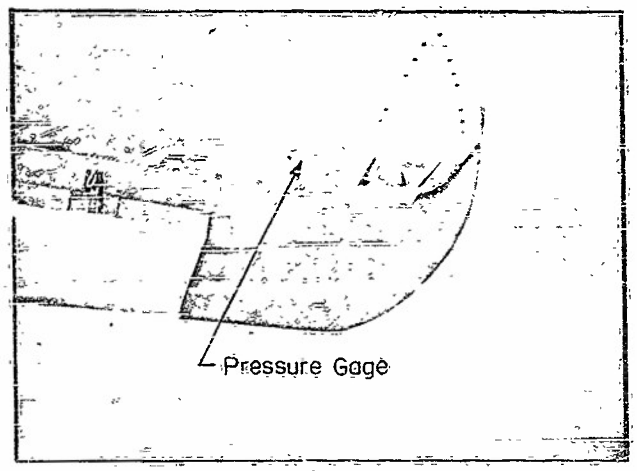


Figure 7c - Gage Position in Lower Surface of Elevator

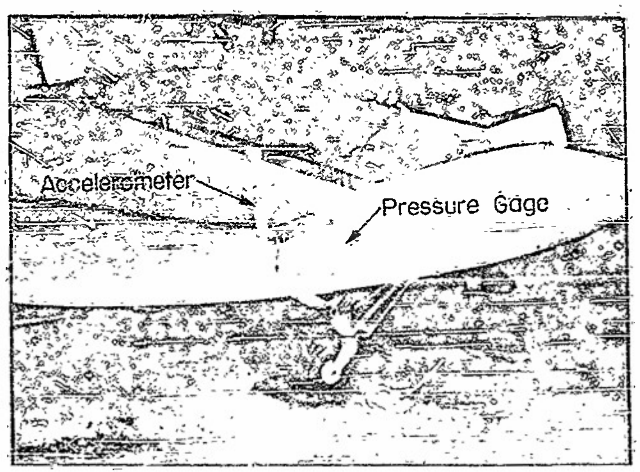


Figure 7d - Gage Position in Upper Surface of Elevator

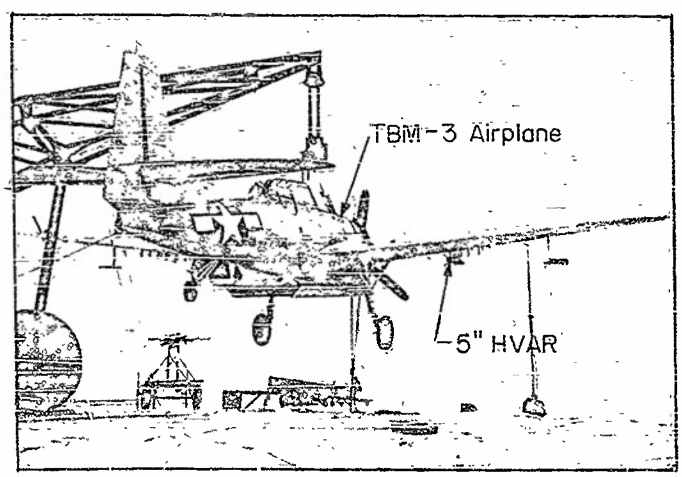


Figure 7e - TBM-3 Airplane Ready for Firing of 5-Inch HVAR's

Figure 7 - TBM-3 Airplane Measurements on $3\frac{1}{4}$-Inch AR's and 5-Inch HVAR's.

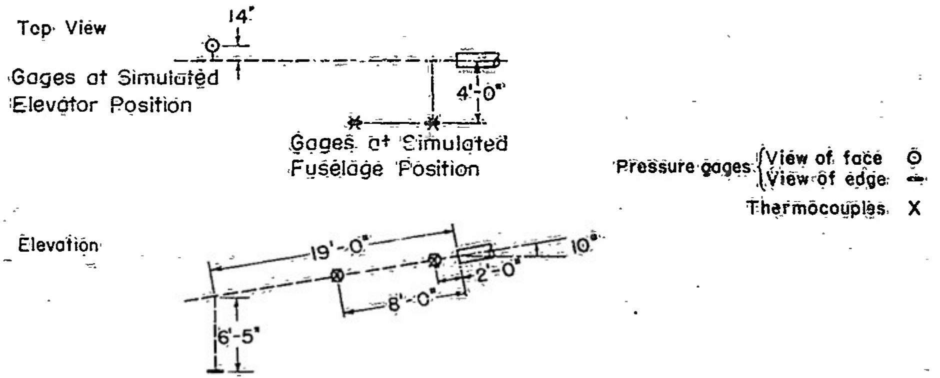


Figure 8a - Diagram of Pressure Gage and Thermocouple Positions

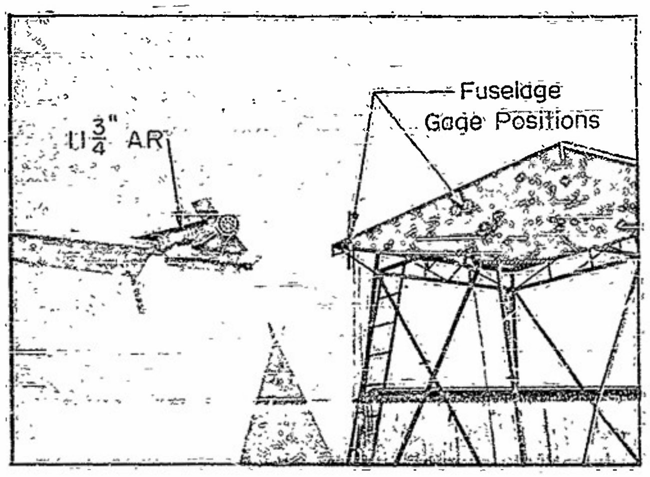


Figure 8b - Simulated Fuselage Positions

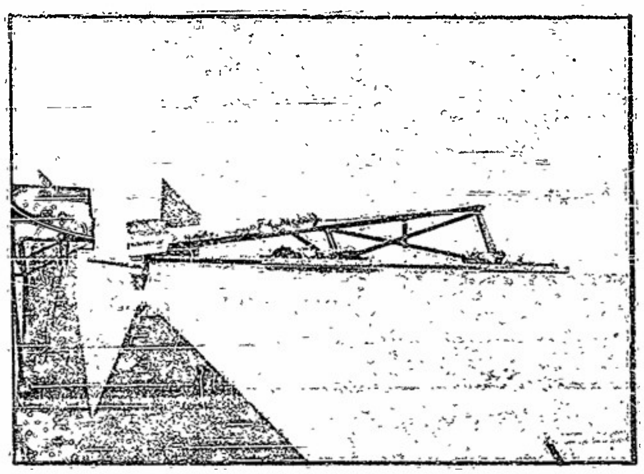


Figure 8c - $11\frac{3}{4}$-Inch AR in Firing Position on Launcher

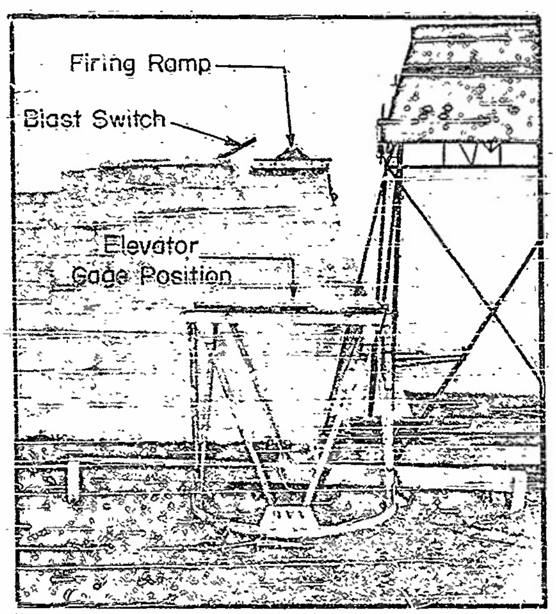


Figure 8d - Simulated Elevator Position

Figure 8 - Test Setup for Field Measurements on 11 3/4-Inch AR's, "Tiny Tims"

Gages are at positions simulating the fuselage and elevator of an SB2C airplane.

measured at three positions whose distances from the rocket corresponded to two points on the fuselage of an SB2C airplane and to a point on the elevator of that type of airplane. As in the other parts of the test, two gages were used at each position, one to measure high-frequency components of short duration and the other to measure lower-frequency components of longer duration. The gage locations are diagrammed in Figure 8a and are shown in Figures 8b and 8d. On Figure 8c is shown the firing attitude of the rocket on its launcher.

As in the field measurements of the first part of the test, the temperature of the blast was measured at the pressure-gage positions with thermocouples.

RESULTS

The results obtained were in the form of several hundred oscillograms showing pressures, accelerations, and temperatures associated with the blast from the various types of rockets. Since it is not practicable to present all the oscillograms, only a few which bring out general characteristics and trends are incorporated in this report, Figures 9 to 18. Specific quantities of primary interest such as peak pressures and positive impulse were measured from the records and have been grouped in three tables corresponding to the three types of rockets used.

Two sets of pressure records from $3\frac{1}{4}$-inch AR's, each obtained under identical test conditions, are presented in Figures 9 and 10. These records are short-duration field measurements obtained at the positions simulating the flap of a TBM-3 airplane, with gages facing down, Figure 9, and up, Figure 10. The considerable spread of the peak pressures is to be noted.

In order to bring out the typical time relationship between the pressures and temperatures found in rocket blast, simultaneous long-duration pressure and temperature records are presented in Figure 11. They were obtained at the simulated flap position, and the pressure gage was facing upward.

In Figures 12 through 16 and in Figure 18, short- and long-duration records obtained at the same gage position are shown together, wherever possible. Most of these pairs of records were actually obtained side by side, during a single firing. Measurements obtained on the TBM-3 airplane and at the corresponding simulated positions have been juxtaposed to bring out individual similarities and differences.

In Figures 12 through 15 are presented sample records of blast pressures, temperatures, and accelerations from $3\frac{1}{4}$-inch AR's and 5-inch HVAR's. Short-duration records are shown as white lines on a black background, while long-duration records are black on white. An effort has been made to show representative records, i.e., those which most closely resemble the average of several records obtained under apparently identical conditions. The records assembled in Figure 12 pertain to the blast effect of a $3\frac{1}{4}$-inch AR at the flap position of a TBM-3 airplane. The left-hand pressure records were obtained at the simulated airplane positions (Figures 6a, 6c, 6d); the right-hand pressure records were obtained on the airplane (Figure 7a). The four top records were obtained with the gage facing down; the next four with the gage facing up. The temperature record was obtained simultaneously with the field measurements, while the acceleration record was taken during the tests on the actual airplane.

The records in Figure 13, also for $3\frac{1}{4}$-inch AR's, were obtained at the elevator position of a TBM-3 airplane. The positions at which the pressure and acceleration records were obtained are shown in Figures 6b, 6c, and 6d and Figures 7c, 7d, and 7e for the field and airplane measurements, respectively. The general arrangement of the records is the same as in Figure 12. No field pressure measurements (for $3\frac{1}{4}$-inch AR's) were obtained at the simulated elevator position, with the gage facing up. There were also no temperature records.

The records in Figure 14 pertain to the blast of a 5-inch HVAR at the flap position of a TBM-3 airplane and are arranged in exactly the same manner as those in Figure 12. The gage positions are shown in the same figures as those for the records of Figure 12.

The records in Figure 15 were obtained with 5-inch HVAR's at the elevator position of a TBM-3 airplane. The general arrangement of Figures 12, 13, and 14 has been followed. No temperature record was obtained. The gage positions are shown in the same figure as those for the records of Figure 13. The pressure, impulse, acceleration, and temperature data from firings of $3\frac{1}{4}$-inch AR's and 5-inch HVAR's are assembled in Tables 1 and 2 respectively. They consist of pressure and impulse data obtained from the short-duration records as well as acceleration and temperature data.

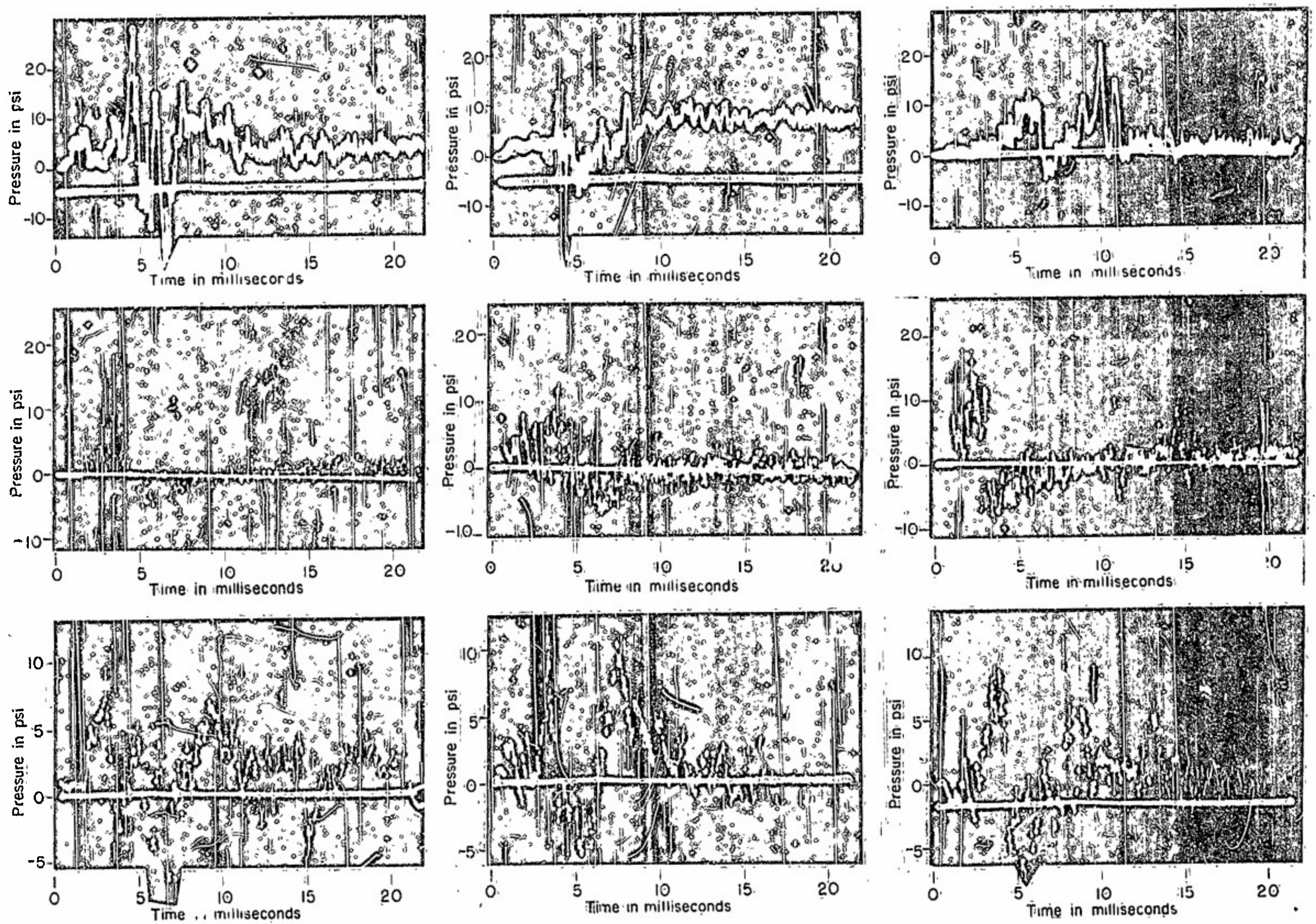


Figure 9 - Records Obtained, under Apparently Identical Conditions, of the Blast Pressures from Nine Singly Fired $3\frac{1}{4}$-Inch AR's

The gage was located at a position simulating the lower surface of the flap of a TBM-3 airplane (Figure 6a).

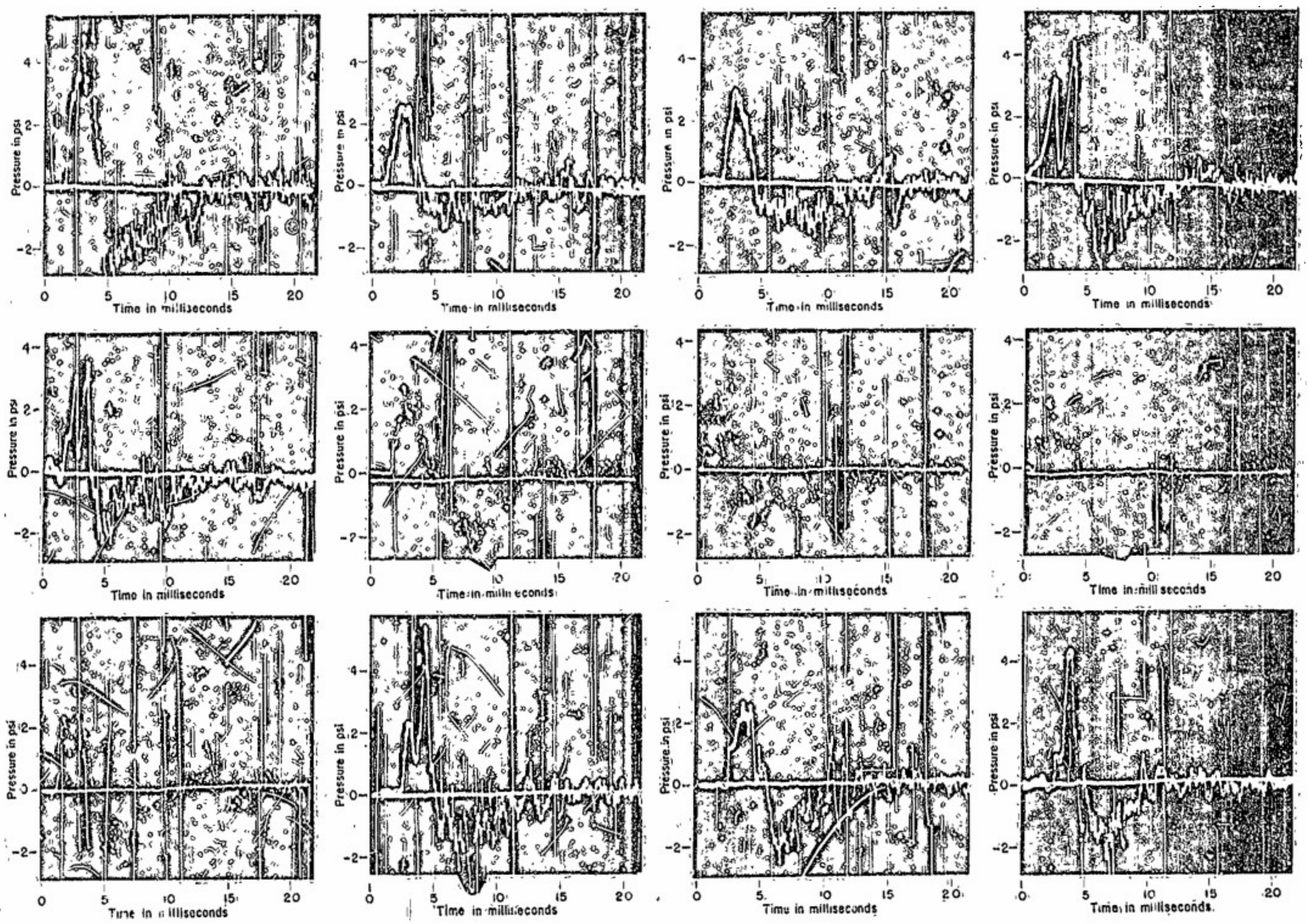


Figure 10 - Records Obtained, under Apparently Identical Conditions, of the Blast Pressures from Twelve Singly Fired $3\frac{1}{4}$-Inch AR's

The gage was located at a position simulating the upper surface of the flap of a TBM-3 airplane (Figure 6a).

Figures 16, 17, and 18 show representative pressure and temperature records obtained from firing of $11\frac{3}{4}$-inch AR's. The short- and long-duration pressure records in Figure 16 and the temperature records in Figure 17 were obtained at simulated fuselage positions of an SB2C airplane (Figures 8a, 8b, and 8c), while the pressure records in Figure 18 were obtained at the simulated elevator position (Figures 8a, 8c, and 8d). Table 3 gives pressure, impulse, and temperature data for $11\frac{3}{4}$-inch AR's. The long-duration records for these rockets were obtained with the channel reliable to 150 cps, and the peak pressures and impulses from the long-duration gage have therefore been included in Table 3.

(text continued on page 28)

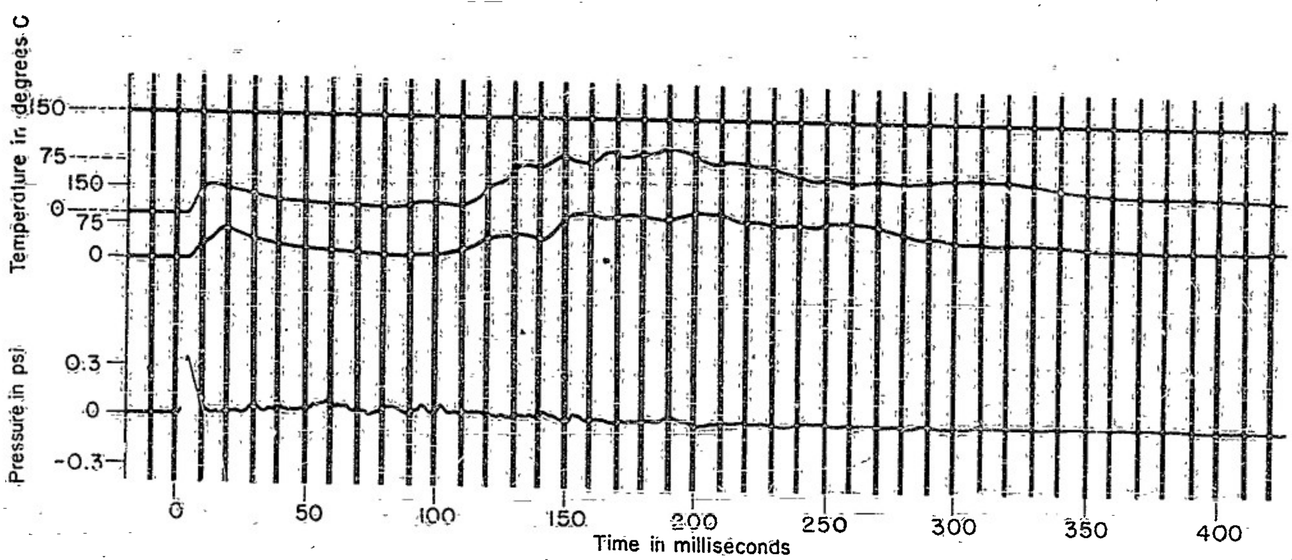


Figure 11 - Simultaneous Temperature and Pressure Records of the Blast from a $3\frac{1}{4}$-Inch AR

The records were obtained at a position simulating the flap of a TBM-3 airplane

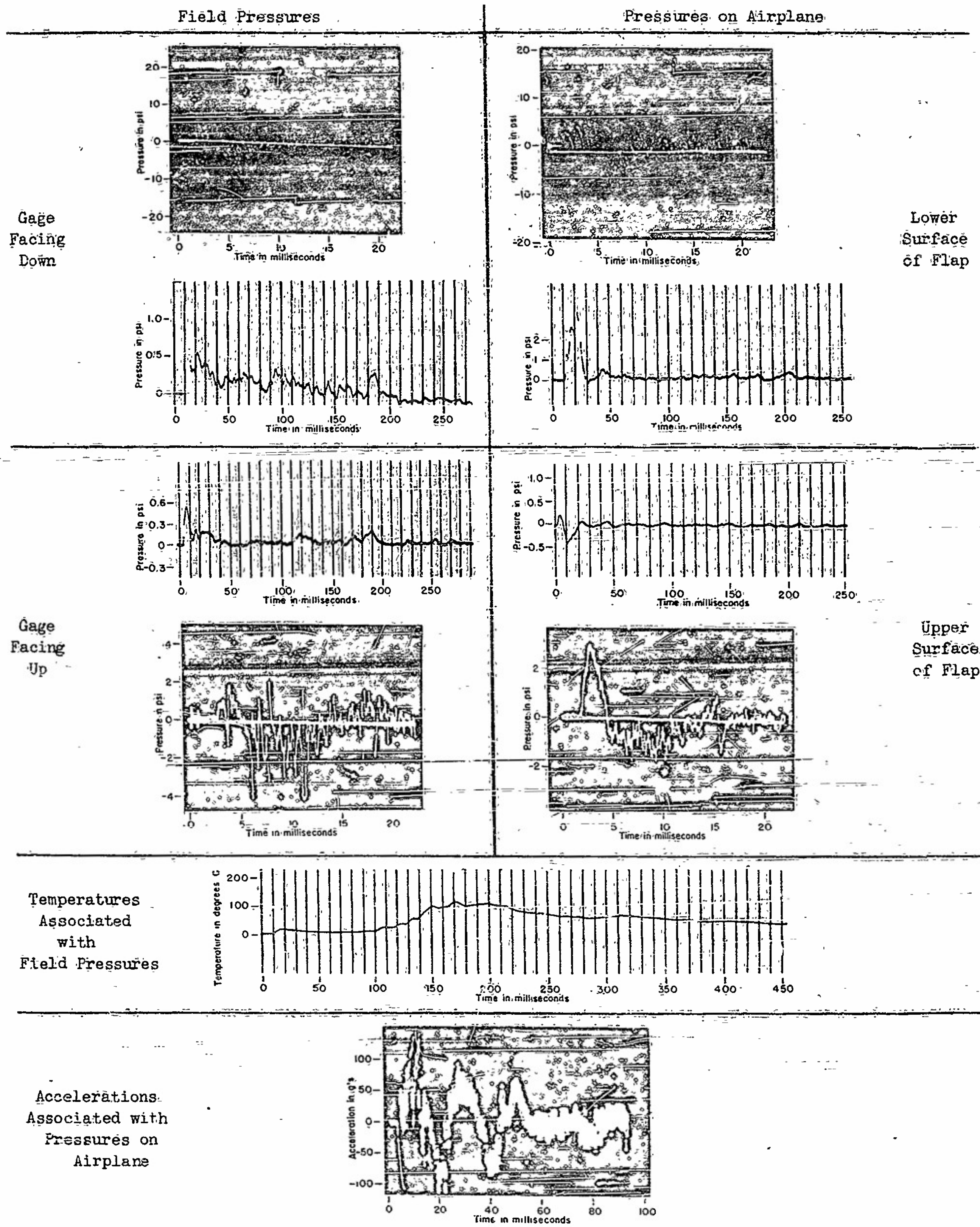


Figure 12 - Pressures, Temperatures, and Accelerations Associated with the Blast from a $3\frac{1}{4}$-Inch AR at the Flap Position of a TBM-3 Airplane

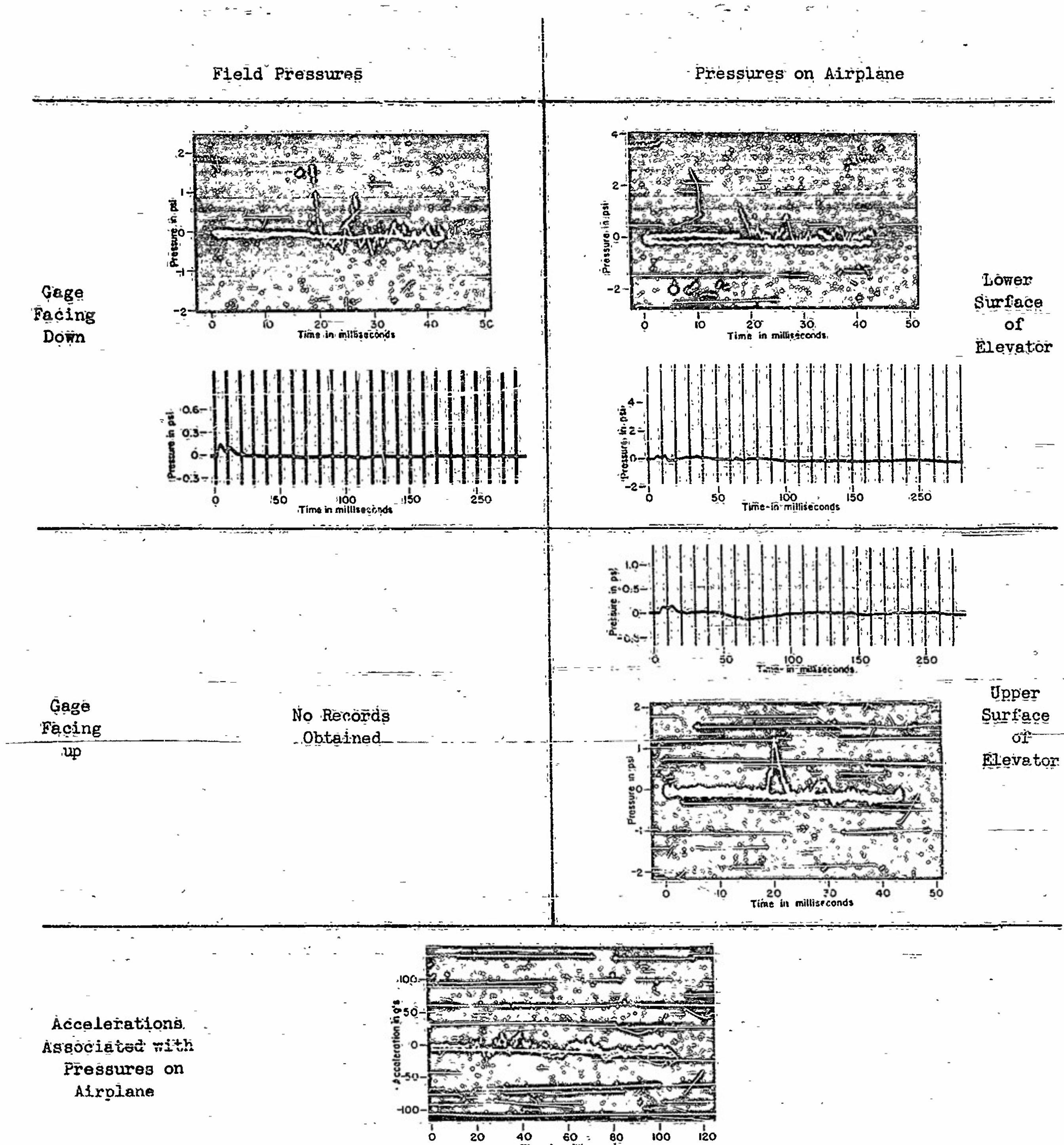


Figure 13. - Pressures and Accelerations Associated with the Blast from a $3\frac{1}{4}$-Inch AR at the Elevator Position of a TBM-3 Airplane

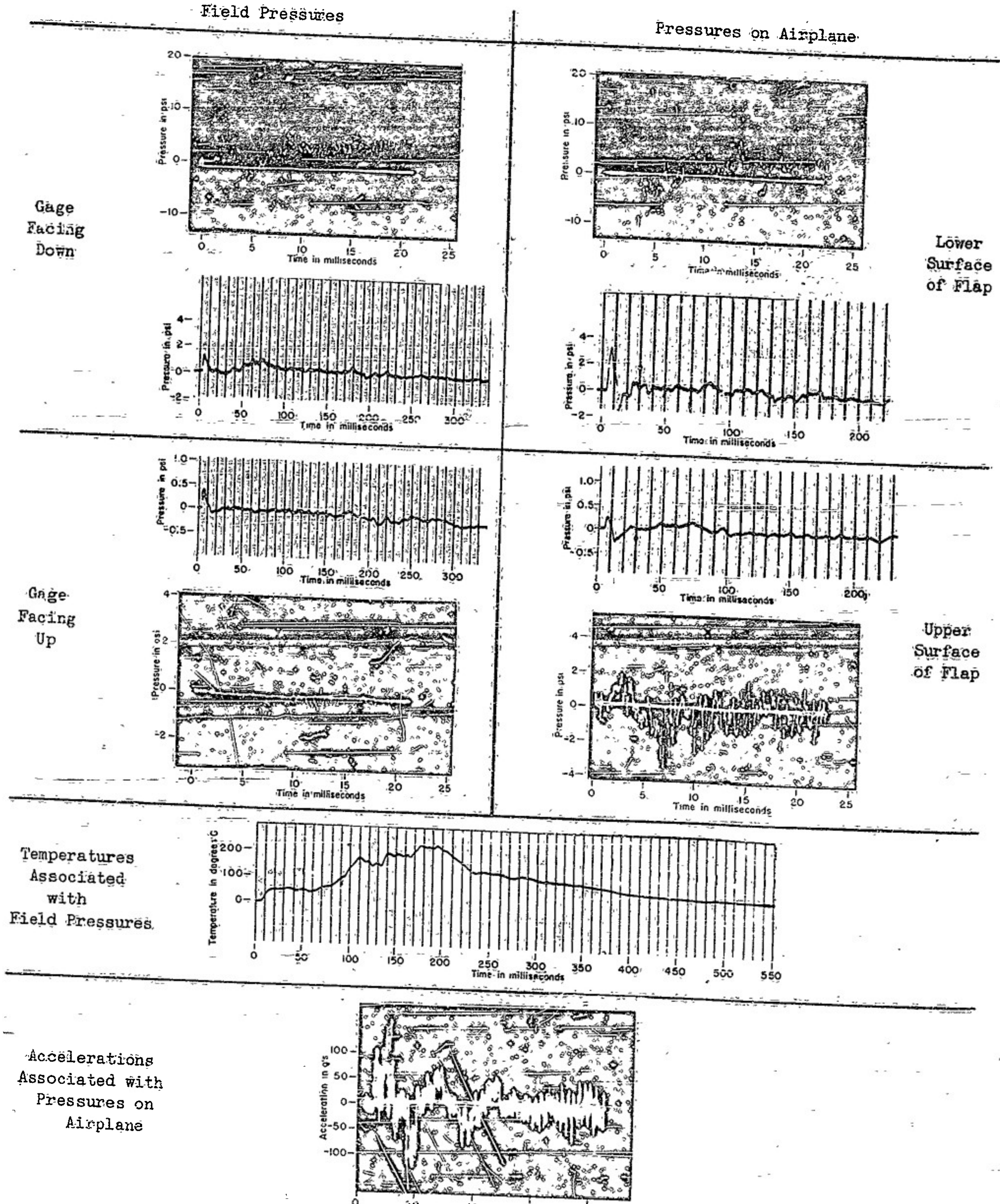


Figure 14 - Pressures, Temperatures, and Accelerations Associated with the Blast from a 5-Inch HVAR at the Flap Position of a TBM-3 Airplane

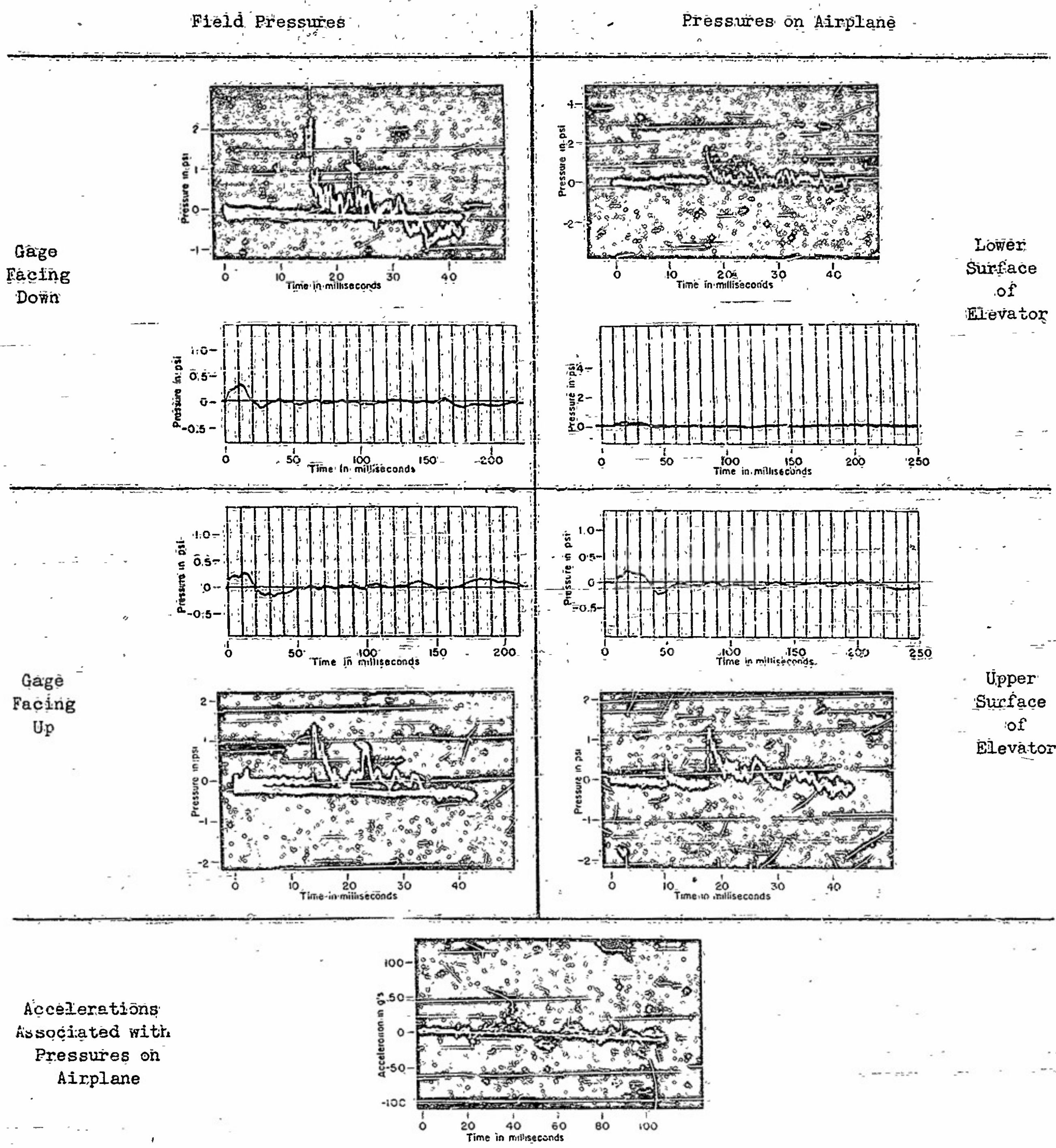
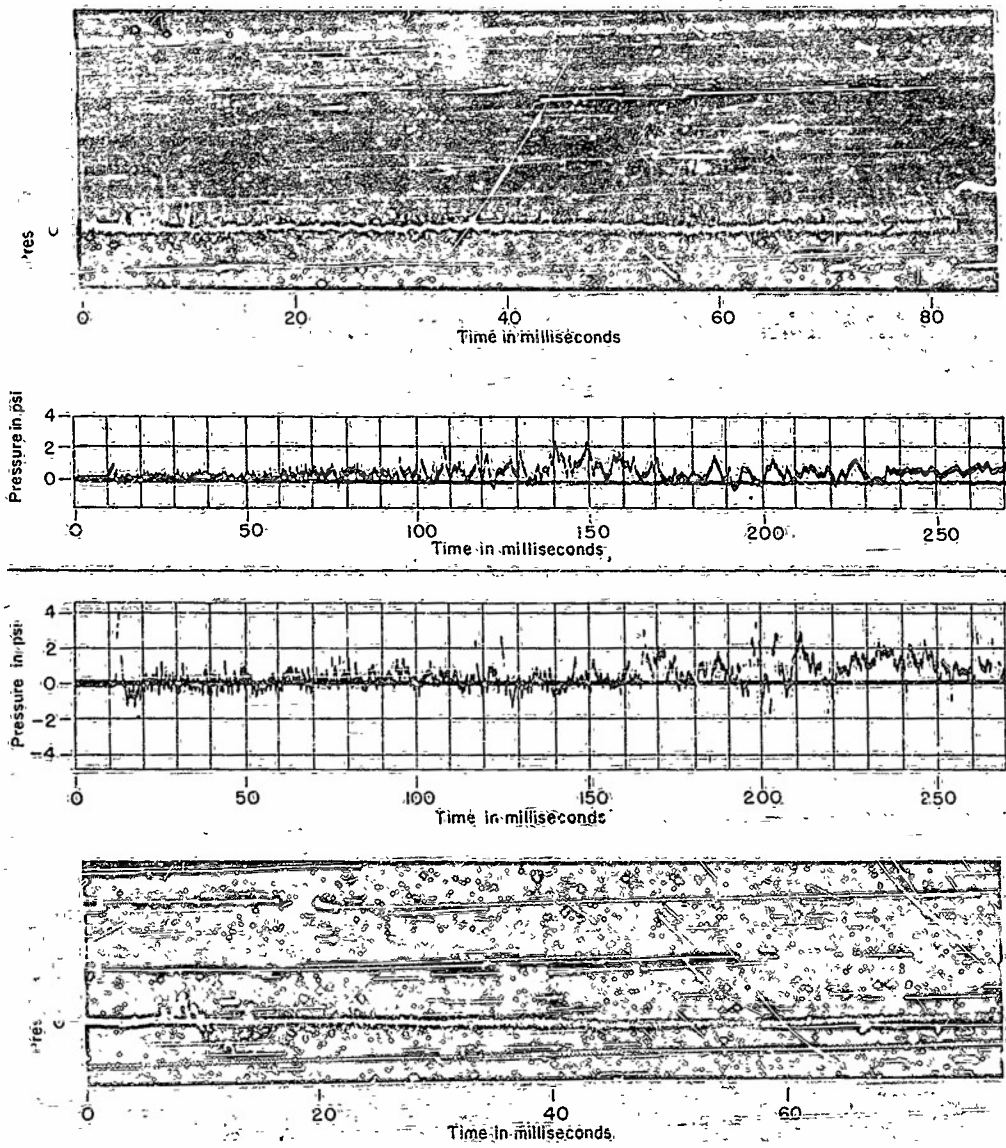


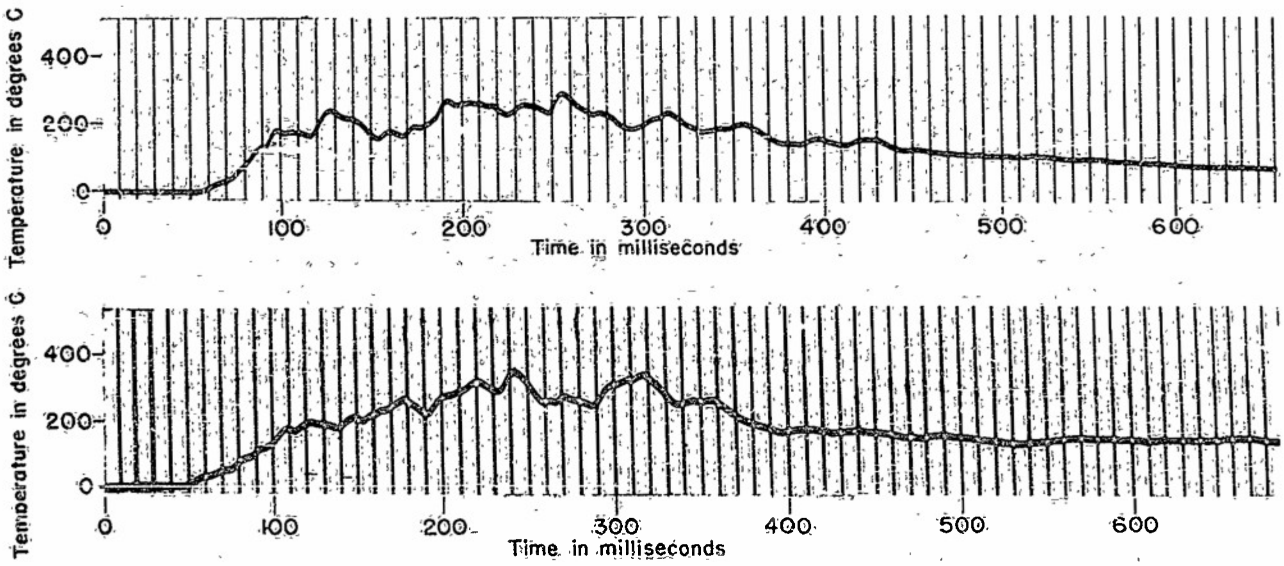
Figure 15 - Pressures and Accelerations Associated with the Blast from a 5-Inch HVAR at the Elevator Position of TBM-3 Airplane



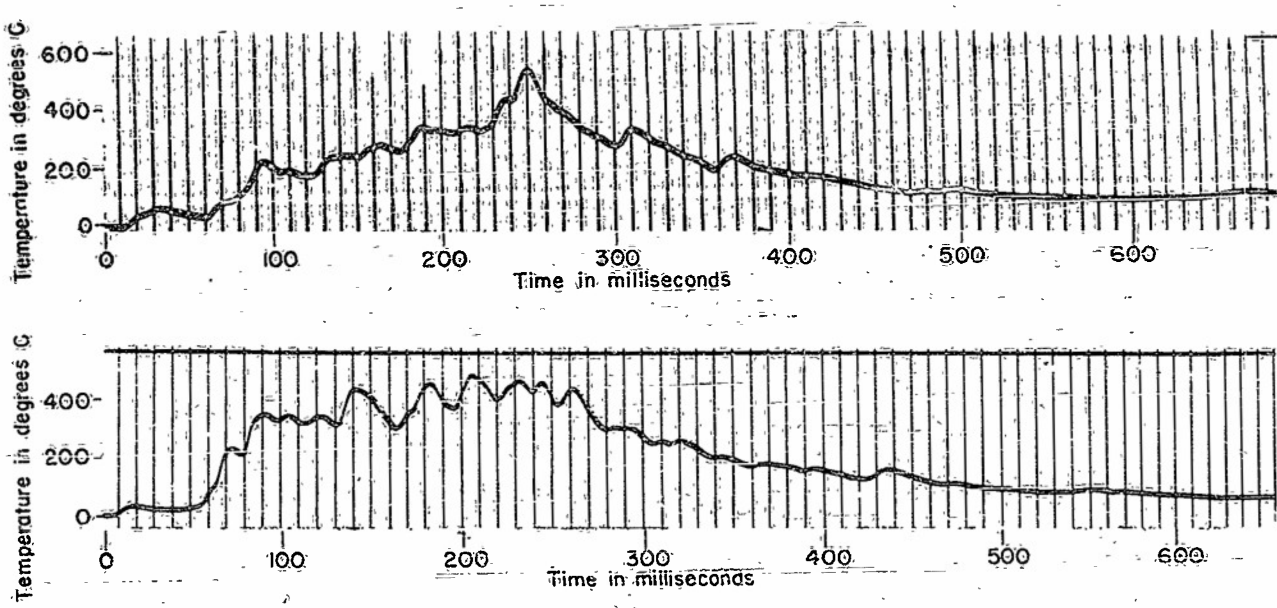
Gages located 2 feet aft of the rocket nozzle and 4 feet off the axis.

Gages located 8 feet aft of the rocket

Figure 16 - Pressures Associated with the Blast from an $11\frac{3}{4}$-Inch AR at Simulated Fuselage Positions of an SB2C Airplane



2 feet aft 4 feet off axis



8 feet aft 4 feet off axis

Figure 17 - Temperatures Associated with the Blast from an $11\frac{3}{4}$-Inch AR at Simulated Fuselage Positions of an SB2C Airplane

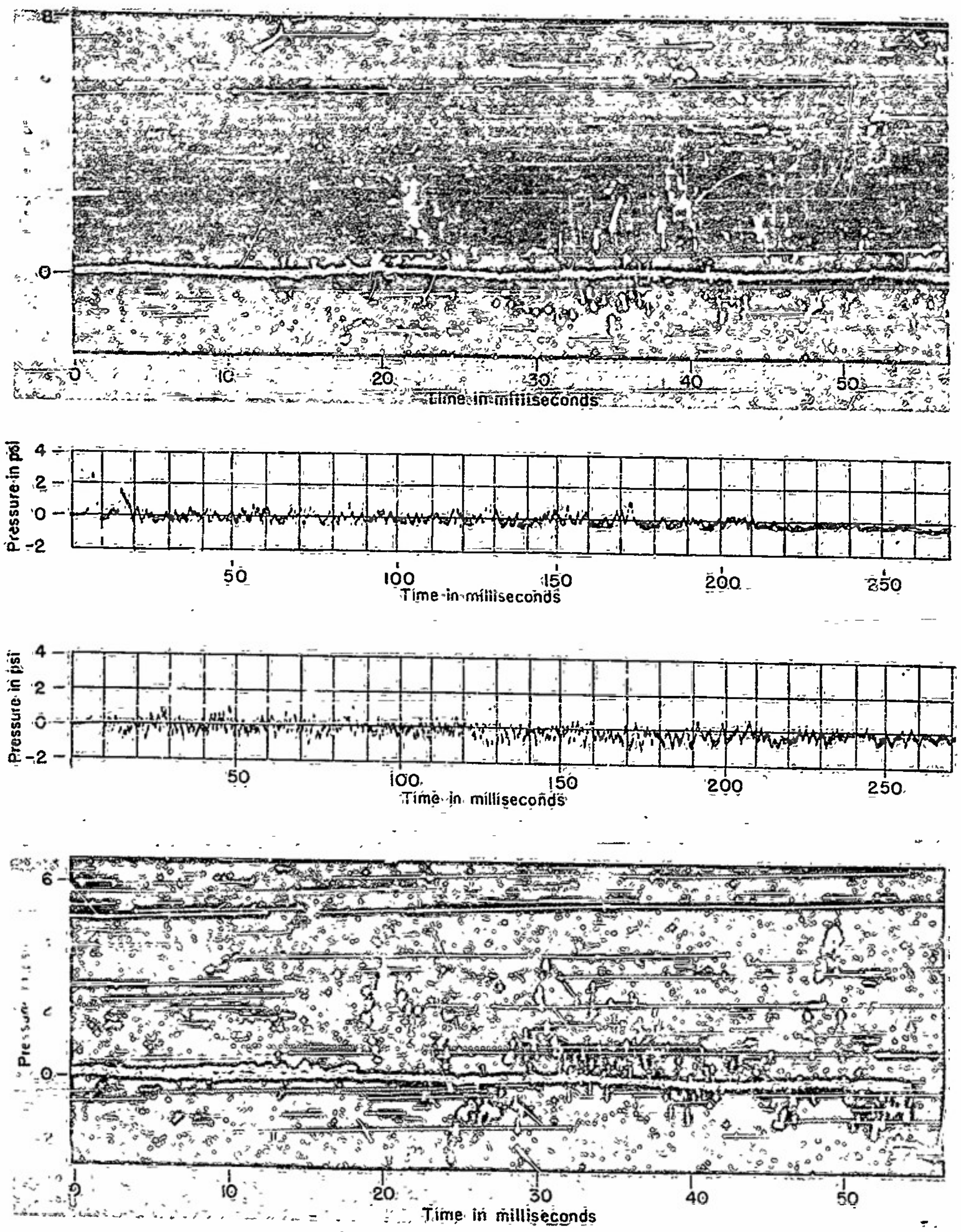


Figure 18 - Pressures Associated with the Blast from an $11\frac{3}{4}$-Inch AR at the Simulated Elevator Position of an SB2C Airplane

TABLE 1

Peak Pressure, Positive Impulse, Temperature, and Acceleration from Firings of $3\frac{1}{4}$-Inch AR's

Position		Peak Pressure in First Positive Pulse, psi		Positive Impulse psi msec		Peak Acceleration on TBM-3 Airplane g's	Predominant Acceleration Frequencies on TBM-3 Airplane cps	Peak Temperature at Simulated TBM-3 Position Degrees C
		Field*	TBM-3	Field*	TBM-3			
Flaps, lower surface	Maximum	26.3	9.7	26.4	10.6			191
	Number of data	11	6	11	6			16
	Average	13.1	7.5	14.6	7.7			142
Flaps, upper surface	Maximum	5.5	2.4	9.0	2.7	153		
	Number of data	15	6	15	6	6	11**	
	Average	3.1	2.0	6.4	1.9	134	50 ± 5	
Elevator, lower surface	Maximum	1.9	1.5	2.6	1.7			
	Number of data	4	4	4	4			
	Average	1.8	1.2	2.4	1.6			
Elevator, upper surface	Maximum		1.5		2.3	23		
	Number of data		4		4	4	8**	
	Average		1.2		2.2	21	33 ± 4 100 ± 10	

*"Field" pressures are baffle pressures recorded at positions simulating the corresponding positions in a TBM-3 airplane.

**Data from 5-inch HVAR's are included.

TABLE 2

Peak Pressure, Positive Impulse, Temperature, and Acceleration from Firings of 5-Inch HVAR's

Position		Peak Pressure in First Positive Pulse, psi		Positive Impulse psi msec		Peak Acceleration on TBM-3 Airplane g's	Peak Temperature at Simulated TBM-3 Position degrees C
		Field*	TBM-3	Field*	TBM-3		
Flaps, lower surface	Maximum	10.5	20.3	8.1	7.1		223
	Number of data	5	8	5	8		6
	Average	9.7	13.3	8.0	6.5		194
Flaps, upper surface	Maximum	4.7	3.3	3.8	3.8	181	
	Number of data	6	3	6	3	5	
	Average	3.6	2.7	3.3	3.3	144	
Elevator, lower surface	Maximum	2.3	1.6	7.5	4.6		
	Number of data	2	4	2	4		
	Average	1.8	1.4	7.4	4.5		
Elevator, upper surface	Maximum	1.4	1.3	6.6	6.3	34	
	Number of data	1	4	1	4	4	
	Average		1.2		6.0	28	

*"Field" pressures are baffle pressures recorded at positions simulating the corresponding positions in a TBM-3 airplane.

TABLE 3

Peak Pressure, Positive Impulse, and Temperature from Firings of 11 3/4-Inch AR's

Position				From Short-Duration Records			From Long-Duration Records			
Aft of Nozzle feet	Off Axis feet	Simulated SB2C Position		Peak Pressure psi	Time of Occurrence of Peak Pressure	Positive Impulse at Start of Record psi msec	Peak Pressure psi	Time of Occurrence of Peak Pressure msec	Positive Impulse at Start of Record psi msec	Peak Temperature degrees, C
2	4	Fuselage	Maximum	5.6	136 msec	3.8	4.3		1.7	343
			Number of data	1		1	7		5	5
			Average				3.3	155±50	1.6	322
8	4	Fuselage	Maximum	10.7	Within first 5 msec	5.1	3.9		5.7	
			Number of data	4		4	5		6	
			Average	7.4		4.3	2.6	2±1	4.6	
			Maximum				3.3			558
			Number of data				5			5
			Average				2.0	140±40		510
19	6.4	Elevator	Maximum	6.7	Within first 5 msec and 31 msec	9.5	4.0		6.9	
			Number of data	2		2	7		8	
			Average	6.2		8.2	3.1	2±1	4.5	

DISCUSSION OF TEST RESULTS

Results from Firings of $3\frac{1}{4}$-Inch AR's and 5-Inch HVAR's

The data for $3\frac{1}{4}$-inch AR's and 5-inch HVAR's show sufficient similarity so that the test results from these two types of rockets can be discussed together.

The great differences among individual rockets of the same type have already been pointed out in connection with Figures 9 and 10. An additional feature of the short-duration records may now be pointed out. Many of them, especially at the flap position, facing down, are characterized by a sudden downward step of the trace, occuring with good regularity 3 to 5 milliseconds after the start of the record. Reference to Figure 11 shows that the first temperature pulse is also observed at the flap position at that time. The possibility had to be considered that this downward step was a dynamic temperature effect caused by the outward buckling of the gage diaphragm due to a temperature gradient instantaneously established from the outside to the inside of the gage. Such a gradient could be developed, for gages close to the rocket axis, by the stream of hot gases expelled by the rocket.

Analysis shows that this gradient would subside almost entirely within a few milliseconds (depending on the thickness and material of the diaphragm). At the same time, the heating of the entire gage would cause a radial expansion of the diaphragm, resulting in a positive tangential strain which would appear as a positive pressure on the record. This second effect might then explain the apparent return of some of the records to a steady level above atmospheric pressure.

Fortunately, these possibilities lend themselves to experimental investigation, and a set of laboratory tests was performed, in which the flame of a "Prestolite" torch was rapidly swept over the face of an unprotected, single-element gage diaphragm. The resulting records are shown in Figure 19. The sharp negative dip followed by a return of the trace to a positive level verifies the presence of both dynamic temperature effects for the gage used in obtaining the short-duration records. A similar test was conducted with the double-element, asbestos-covered gage. There was no instantaneous effect with this gage, and a relatively slow downward drift of the trace was observed. This is readily explained as an effect of the temperature differential between the two strain elements.

In evaluating the records presented, the following features must be remembered in view of the above results:

(a) Sudden dips, occurring in short-duration records 3 to 5 milliseconds after the start and recovering in a few milliseconds, should be ascribed at least in part to temperature rather than pressure.

(b) The average level of short-duration records should not be trusted after such a dip, since it is established at least partially by temperature.

(c) A steady downward trend observed in long-duration records is a temperature effect.

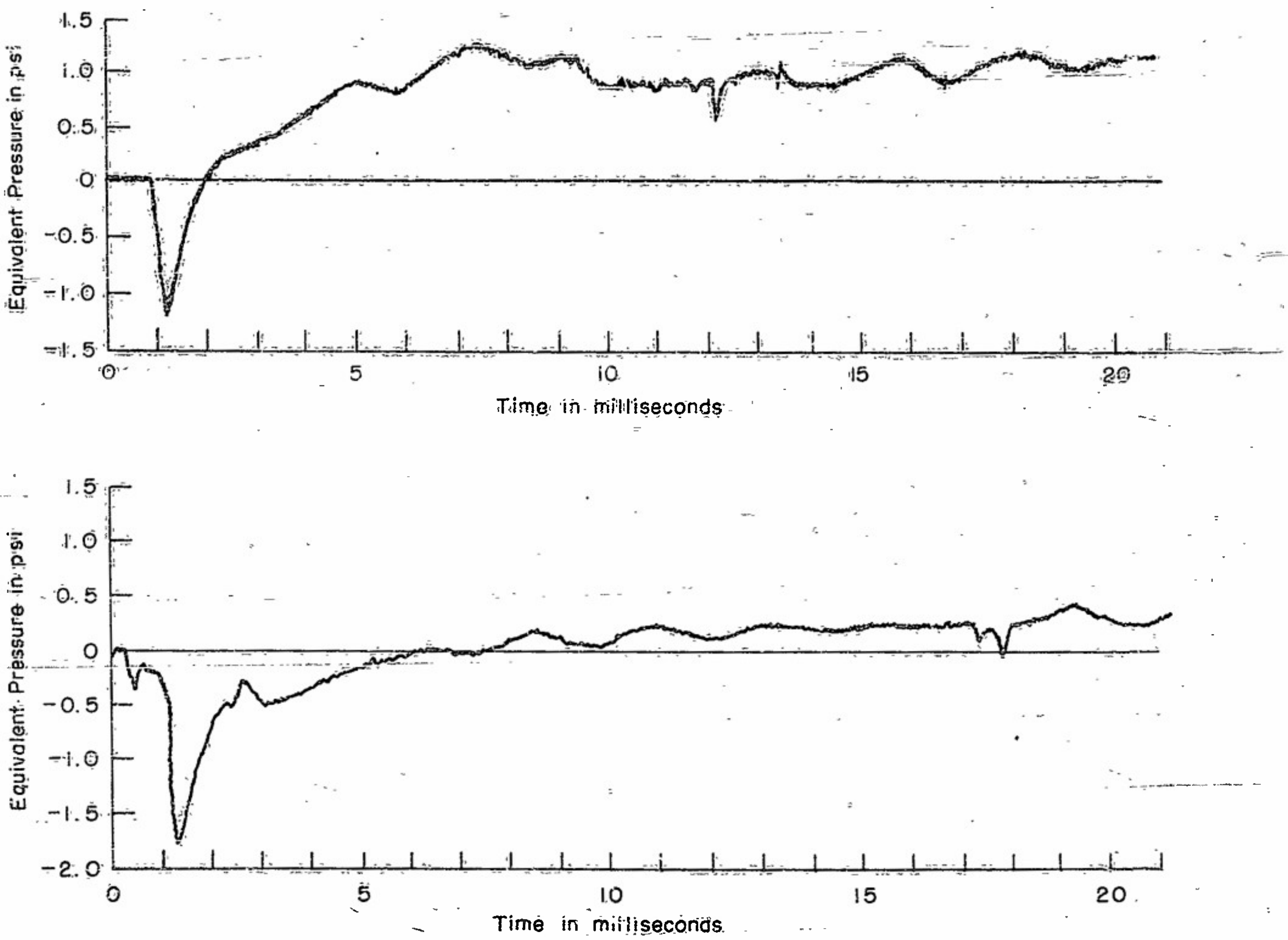


Figure 19 - Dynamic Temperature Effect for the Unprotected Short-Duration Pressure Gage

These records were obtained by rapidly sweeping across the face of the gage the flame from a "Prestolite" torch. The differences in the two records may be ascribed to slightly different sweeping rates.

The use of the high-frequency, short-duration gage and channel made possible an estimate of the order of magnitude of frequencies that were high and also resolved the details of the high-pressure initial phase. These initial phases for different gage locations and both types of rockets can be seen to consist of an initial peak composed of several secondary sudden rises, which are believed to be due to shock waves, either from the rocket ignition charge or in the gas flow. The considerable differences in recorded peak pressures are due to the difference in frequency response of the short- and long-duration recording channels. It will be seen that the remaining discrepancies between the short- and long-duration records can be accounted for by the above temperature effects.

Throughout these records, it is apparent that the general characteristics of the pressure from the aircraft firings were the same as those from the field firings. This shows that the baffles in which the gages were mounted for the field firings were sufficiently large to simulate the aircraft control surfaces for the important frequency components of the pressures. It is believed that the differences between the respective average values of peak pressures and impulse are within the spread inherent in the performance of rockets and of no experimental significance.

As might be expected, the temperature dips are most pronounced at the gage position on the lower surface of the flap. They do not seem to interfere with the recording of peak pressures which usually occur earlier in the record. An estimate of the true positive impulse, however, becomes quite difficult. The values given in Tables 1 and 2 were obtained by integrating the apparent positive impulse in the short-duration records and are almost certainly too low. This assumption may be verified by reference to the long-duration pressure records in Figures 12 and 14 in which the positive pressure phase has a duration of 20 milliseconds or more for $3\frac{1}{4}$-inch AR's and about 10 milliseconds for 5-inch HVAR's.

The peak pressure at the lower surface of the flap is of the order of 15 psi, with the peak pressure from an occasional rocket as high as 25 psi or more. The positive impulse cannot be reliably given from these records but almost certainly reaches 40 psi-milliseconds or more in some records.

At the upper surface of the flap, the pressure and temperature effects are much milder, showing that the diffraction of the pressures is slight, and the values given in Tables 1 and 2 can probably be trusted. At the elevator position, the double pressure peaks are resolved in both short- and long-duration records and must be considered reliable. The second peak is probably due to reflection from the ground. It is believed that the 10-millisecond spacing of these pressure peaks is responsible for the brief but strong 100-cps component in the corresponding acceleration records.

The temperature records probably do not have high accuracy because of unavoidable thermal lag in the thermocouples. This is particularly true of the first heat flash at the beginning of the record, which high-speed pictures show to be caused by a single puff of flame traveling at a speed of about 1500 feet per second. The records should, however, give a useful indication of the history of the temperatures present.

The pressure loading on the flap from simultaneous salvo firings was appreciably more severe than that from single firings. The record from a test with four 5-inch HVAR's nominally fired simultaneously showed a peak pressure of 19 psi. This pressure was in the initial phase and may have been due to two or more of the rockets actually firing simultaneously. A secondary peak, with a pressure of 9 psi, followed; this peak was possibly due to the delayed firing of the other rocket or rockets (the delay being due to difference in igniting time). After this there was a region of pulsating pressure with a maximum value of about 9 psi and a fundamental frequency of 300 cps. This phase lasted for about 30 milliseconds, and then the pressures started to subside. Only one reliable record of the blast from a four-rocket salvo was obtained, and presumably some of the details of the initial phase may vary with the difference in ignition times of the rockets in the salvo.

The subsidiary test to determine the effect of varying the launching angle of the rocket had only one notable result, namely, in the +4° position, to cut out the dynamic temperature effect on the short-duration gage. The peak positive pressures and pressure frequencies were not changed to any great extent.

<u>Results from Firings of $11\frac{3}{4}$-Inch AR's, "Tiny Tims"</u>

The final portion of the test was the field measurement of the blast pressures and temperatures from $11\frac{3}{4}$-inch AR's ("Tiny Tims"). The histories of the pressures from the "Tiny Tims" depended on the position at which they were measured, as shown in Figures 16 and 18 and in Table 3. At a position 4 feet to the side of the rocket axis and 2 feet behind the nozzle--Figure 16a--the highest pressures occurred on the average about 150 milliseconds after the pressure onset. These high pressures were vibratory, but no specific frequency could be assigned to them. The frequencies were composed of higher modes superimposed on lower ones. The duration of the pressures at this position averaged about 290 milliseconds.

In the position 4 feet to the side of the rocket axis extended, and 8 feet aft of the nozzle--Figure 16b--the records more nearly resembled those obtained from the smaller rockets. The maximum pressure occurred at the very start. About 180 milliseconds later, there was another region of vibratory high pressures, although these were not as great as the initial pulse. The duration of the pressures at this position was about 275 milliseconds.

The final position studied was the elevator position, Figure 18. Here again the peak pressure occurred initially. About 20 milliseconds after the first peak came another of amplitude nearly as great, and yet another 30 milliseconds after the start. These peaks can be seen in Figure 18. After this, the pressure essentially oscillated about zero, with a few secondary peaks, but generally with a steadily decreasing amplitude--as can be seen from typical long-duration string-oscillograph records shown in Figure 18. The pressure duration at the elevator position averaged about 270 milliseconds.

Temperature measurements were made at the two positions 2 feet and 8 feet behind the nozzle and 4 feet to the side of the rocket axis. It can be noticed, from the pair of duplicate records in Figure 17 and from the data in Table 3, that the nearer thermocouple is not acted upon by the jet of the rocket as severely as the farther one. This happens probably because the jet is not very wide at the 2-foot position.

CONCLUSIONS AND RECOMMENDATIONS

It should be stated that this report is primarily factual, presenting the results obtained during the test with little attempt to interpret them. Many measurements were taken, and it was found that the scatter of the results was quite large--± 30 percent or more. The results as given are both average and maximum observed values. The large scatter is principally due to the inherently somewhat inconsistent nature of rockets. The measurements taken show that the blast pressures behind rocket motors are a complicated phenomenon, consisting of low-frequency components on which is superimposed a range of higher frequencies. Most records are characterized by an initial positive peak lasting up to a few milliseconds. The initial positive phase is probably contributed to greatly by the shock waves from the igniter charge. In order to reduce the shock-wave pressures, the igniter charge should be cut down to the minimum value at which the rocket will still fire.

A relatively long-duration negative phase may also be present immediately after the initial positive phase, but its existence was made uncertain by considerable dynamic temperature effects.

Recorded oscillating pressures may well be due to turbulence in the region of the jet and to shock waves in the jet. Damage to the airplane members under test may be enhanced by the vibratory character of the pressures, especially those of lower frequencies.

Simultaneous firings of several rockets in a salvo increase the peak pressures considerably, and thus individual firings in a salvo should be staggered by at least 0.1 second to decrease the peak load on structures exposed to the blast. Little or no relief except for temperature effects can be obtained by small variations in the launching angle of the rockets.

These preliminary tests were designed to bring out the characteristics of the blast pressures from rockets. Since the pressures are probably strongly dependent on position, a much more complete map of the pressure field behind rocket motors should be undertaken. Moreover, the pressures from dynamic rocket firings in still air, such as those reported, may be quite different from those in the air stream--as when rockets are fired from a flying airplane. Pressure measurements in flight thus seem necessary, with the philosophy that if a correlation could be obtained between the pressures in flight and in still air, only ground firings would be necessary for extensive maps of the pressure field. The problem of obtaining such a correlation would probably be quite difficult, however.

As has been pointed out before, the pressure measurements during this test were undertaken by the use of a short-duration, high-frequency channel and a long-duration, low-frequency channel, in order to obtain a comprehensive picture of the frequency spectrum of the blast pressures. This procedure was necessitated by the press of time and lack of more suitable instrumentation. Such an arrangement is not desirable, because an accurate, quantitative picture of the phenomena cannot be obtained. The results of the tests described in this report showed the necessity of constructing a pressure gage and associated electronic channel that would measure faithfully pressures with a frequency spectrum ranging from zero to at least 15,000 cps. Once the nature of the rocket blast pressures is known quantitatively and the most damaging frequencies (probably fairly low) are established, the recording equipment could be narrowed in its range, if this would simplify appreciably the task of mapping the pressure field.

As a result of these preliminary investigations, quantitative requirements* for a complete pressure-measuring and recording channel were drawn up[10] in a meeting between representatives of the Naval Ordinance Test Station and of the Taylor Model Basin.

PERSONNEL

The tests were carried out by Ens. P. Tamarkin, B. Sussholz, W. P. Kiley, P. Hendrican, and A. Menzak from the Taylor Model Basin, and by Lt. (jg) J. Hundley of the Armament Test Unit, Naval Air Station, Patuxent River, Maryland. The results were analyzed at TMB by P. Tamarkin and T. A. Perls with the assistance of Frances Long and W. E. Carr.

*These requirements led to the development of a condenser-type pressure gage and associated resonant-bridge carrier system which are described in References 11 and 12. Sample rocket records obtained with this new instrumentation are presented in References 13 and 14.

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(14) Perls, T. A., Ph.D., "Blast Pressures Recorded during Launching of 5-Inch High-Velocity Aircraft Rockets from a Type PV-2 Naval Patrol Bomber," TMB CONFIDENTIAL Report C-93, May 1948.

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